Predator Effects on Dense Zooplankton Aggregations in the Coastal Ocean

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LONG-TERM GOALS

The distribution of organisms in the ocean is highly heterogeneous, influencing both sampling and ecological structure. The complex spatial and temporal structure of predators and prey affect one another. Numerous studies in pelagic systems have investigated the effects of prey distribution on predator behavior and studies in benthic habitats have revealed the significant impacts predators can have on prey distribution. However, primarily because of sampling difficulties, few studies have investigated the effects of predators on prey distribution in pelagic systems. In the last decade, advances in measurement capabilities have led to the discovery of plankton aggregations over continental shelves with vertical dimensions of tens of centimeters. These 'thin layers' can have a horizontal extent of several kilometers and may persist for days. Sharply distinct from the surrounding water column, the density of phytoplankton and zooplankton in these layers can be orders of magnitude higher than at surrounding depths. The discovery of these ubiquitous layers of plankton has opened up new possibilities in studying aggregation in the ocean. The long-term goal of this work is to understand the ecological importance of thin layers of plankton

OBJECTIVES

- Determine the scales of aggregation of acoustic scatterers in the coastal ocean
- Understand the role of predation in determining the scales of these aggregations
- Assess the impact of the interaction of predators with aggregations of prey animals on the performance of acoustical and optical sensors.

APPROACH

Extremely thin aggregations of zooplankton recently described in a number of coastal systems will be used as the experimental model for addressing these questions. These extremely thin aggregations persist over long time periods, are relatively predictable, and are being intensively studied in Monterey Bay, California as part of the ONR funded Layered Organization in the Coastal Ocean program (LOCO). I will work collaboratively with the investigators of this project to integrate my sampling approach into the existing program, adding a significant new component to the work while leveraging their resources to address the general biological questions of patchiness and scale in predator-prey interactions that are the focus of my research. The advantage of leveraging this project is the availability of substantial vessel time, supplementary data, and concomitant sensing with other techniques.

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Specific methods:
Continuously *map the distribution of acoustically scattering thin layers* looking for variations in depth and intensity using a five-frequency split-beam echosounder. Specifically, I will determine where thin layers are absent either through total loss in an area or in small gaps or breaks. Geostatistical techniques will be utilized to characterize the scales of aggregations, their spacing, and the features of edges.

Compare the results of synoptic surveys for *acoustically scattering and optically scattering thin layers*. This work will be done in collaboration with B. Concannon and J. Prentice who will be conducting concomitant LIDAR surveys. More than just comparing the two techniques, our goal is to determine if differences in acoustical and optical scattering can be related to the identity or distribution of organisms in these layers. We propose that the combination of optical and acoustic scattering can be used in a way analogous to looking at acoustic frequency spectra and using inverse processing techniques and may provide more information than adding additional frequencies to either technique alone.

Use a series of moored echosounders to *determine if larger scatterers* that may be consumers of organisms within thin aggregations *are regularly present over the shelf* in shallow waters either through advection of diel migrators or through active diel horizontal migration. I will compare the depths of these potential predators to the depths at which thin layers are detected at the same time during ongoing zooplankton process studies. Comparison of changes in the depth of both the thin layers and the larger animals may reveal tracking of the layers by its consumers.

Use a multibeam sonar to *detect relatively large individual, mobile acoustic scatters* both inside and outside thin aggregations of zooplankton. The data will be used to observe their behavior as well as to quantify the intensity and distribution of the thin layer to *determine if these larger animals appear to be foraging inside thin, horizontal layers* and what changes in the layers are correlated with their presence either as an immediate, observable response or statistical difference.

Utilize data to *predict acoustical and optical signal attenuation* as a function of scales of aggregations, their density, and composition. Dense aggregations of organisms can cause significant signal transmission loss and distortion. The variability in biological sources of scattering causes difficulties in predicting these losses. Data from the various approaches will be integrated to understand and predict how predation on dense aggregations can affect signal transmission in the coastal ocean.

WORK COMPLETED

The second field season for the project was completed in Monterey Bay, California in August, 2006 as part of the LOCO program. Four active acoustic moorings were deployed between July 12 and August 29, 2006 (bracketing the cruise) to look for acoustical scattering from micronekton and nekton and the possibility that these predators may be present over the shelf through advection and trapping of diel migrators or through active diel horizontal migration. The onshore movement of predators could be important for the persistence of thin layers of zooplankton and the diel behavior of these animals. Predators like small fish and other micronektonic animals could have cascading effects, releasing phytoplankton from grazing pressure and indirectly affecting layers of primary producers.

Collaboration with investigators who deployed other instruments in this area over the same time period as part of the LOCO program will provide an important physical and biological context for

understanding the observed patterns from the active sonar moorings and their importance. The underwater winch profilers (Donaghay and Sullivan, University of Rhode Island), moored acoustic Doppler current profilers (McManus, University of Hawaii), and thermistor chains (McManus) will provide information on physical processes at the site that will help separate the processes underlying inshore predator movement, trapping or active migration. Surveys with a turbulence and fine-structure autonomous underwater vehicle (REMUS, Goodman, University of Massachusetts at Dartmouth) within the study region will describe the fine-scale sheer and density structure that may directly drive the aggregation of food resources for these predators. Moored Tracor acoustic profiling systems (TAPS, Holliday and Greenlaw, BAE Systems) will describe the distribution of zooplankton in the area. The distribution of larger animals will be compared to the distribution of their potential prey, physical structures, and current patterns.

Between August 11 and August 29, 2005, our research team participated in the LOCO program aboard the R/V Thomas Thompson. Surveys of the horizontal and vertical distribution of sonically scattering organisms were conducted in Monterey Bay, CA . Split-beam scientific echosounders operating at 38, 70, 120, and 200 kHz (Simrad EK 60s) and a 710 kHz single beam (Simrad EQ 60) were used to map the distribution of acoustic scattering layers. The use of split beam technology permits measurement of target strength as well as echo integration measurements. Previous studies of thin layers have determined that to effectively detect and characterize thin layers requires a vertical sampling resolution of less than 1 m, which were achieved with all the proposed frequencies.

In addition to ship-based acoustics, acoustic data were collected using the Tracor Acoustic Profiling System (TAPS) mounted to a CTD with a fluorometer. This data will be important in separating fish and zooplankton scattering. Data from these profiles also provides coherent phytoplankton vertical distribution.

Between August 10 and September 9, 2006, our research team participated in the LOCO program studies aboard the R/V Shana Rae. We conducted surveys using two split-beam echosounders, 38 and 120 kHz, and a 200 kHz multibeam sonar. We also conducted focused studies using the multibeam sonar on a rotating motor to allow three-dimensional imaging of a single volume of water over time.

Substantial data analysis has been completed over the last year, resulting in two presentations at major international meetings:

Benoit-Bird, K.J. “Three-dimensional structure of thin zooplankton layers is impacted by foraging fish” 2008 Ocean Sciences Meeting, Orlando, FL. March 3-7, 2008.

Benoit-Bird, K.J. “Three-dimensional structure of thin zooplankton layers is impacted by foraging fish” Acoustics ’08. Paris, France. June 30-July 4, 2008 (invited presentation).

In addition, two papers are in the final stages of preparation for publication, one as part of the LOCO DRI’s special issue of Continental Shelf Research.

RESULTS

Data synthesis for this program is ongoing. Our results suggest that in 2005 and 2006, zooplankton thin layers were rare during daylight hours inside the study area. However, nighttime layers were frequently observed in the upper 10-12 m of the water column. Moorings in four locations within the study area

provide a temporal record of thin layer presence (Figure 1). The observed pattern of thin layer distribution changed dramatically as we moved offshore, indicated by both the array of moorings and the boat-based surveys.

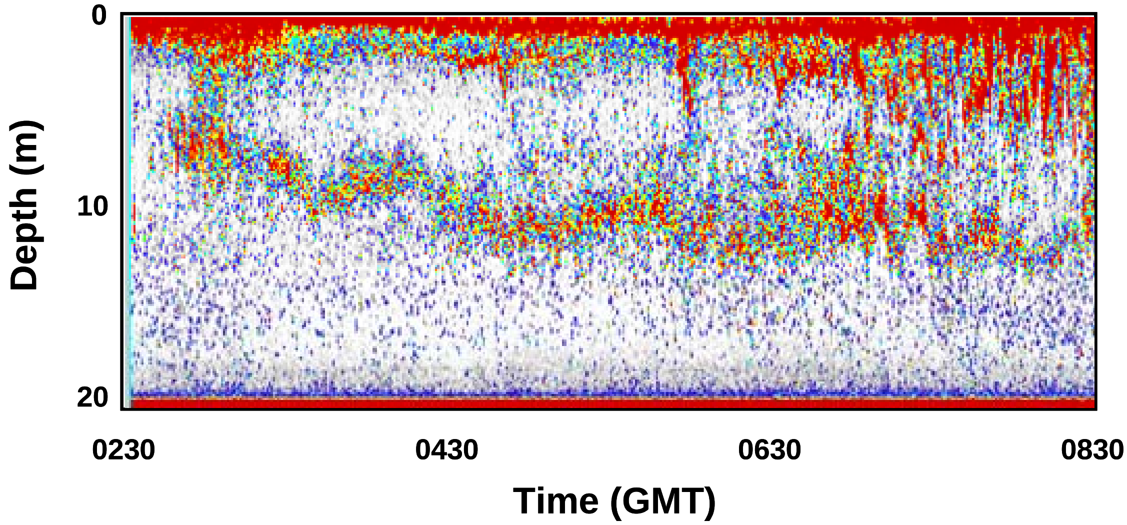

Figure 1. A 6-hour time-record of acoustic scattering at 200kHz from a moored, upward-looking echosounder. A relatively strong scattering layer appears just after 0230 GMT, 1930 local time, and persists until after 0830 GMT, 0230 local time. The depth of the layer varied greatly over the 6 hours shown, moving deeper as additional, large scatterers are evident in the surface waters.

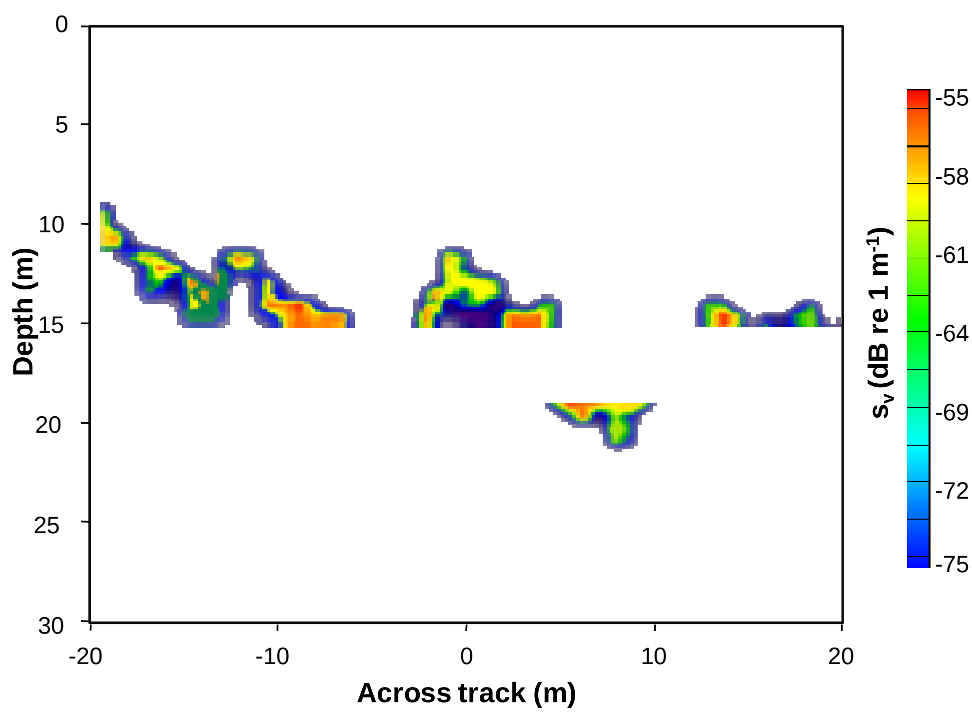

Figure 2. Backscattering at 200kHz from a single ping from multibeam sonar. The seafloor is just visible at 30 m. A thin layer of zooplankton is evident between 10 and 20 meters. The layer is deeper to the right of the vessel and shallower to the left of the vessel.

Scattering by thin layers of zooplankton was captured by the 200 kHz multibeam sonar (Figure 2), providing a 3 dimensional view of the layer. This high-resolution view of layers is providing information on how they are structured in space as well as in time and is showing the interaction with physics and predators.

Similar to the 2005 field effort, during the 2006 cruise, we found extremely high densities of fish inside Monterey Bay. Unlike the previous effort where fish were observed primarily at night, dense aggregations of fish were observed both during the day and at night in 2006, primarily as relatively small schools. Using the multibeam sonar, we were able to image these schools (Figure 3). We found that there were differences in there geometry and internal structure that could not be identified using a standard echosounder. We were also able to observe behavioral interactions between fish and zooplankton in real time, allowing us to adapt our sampling. Further processing of this data has shown that fish grazing is important in shaping zooplankton thin layers and plays a signficant role in their formation and persistence.

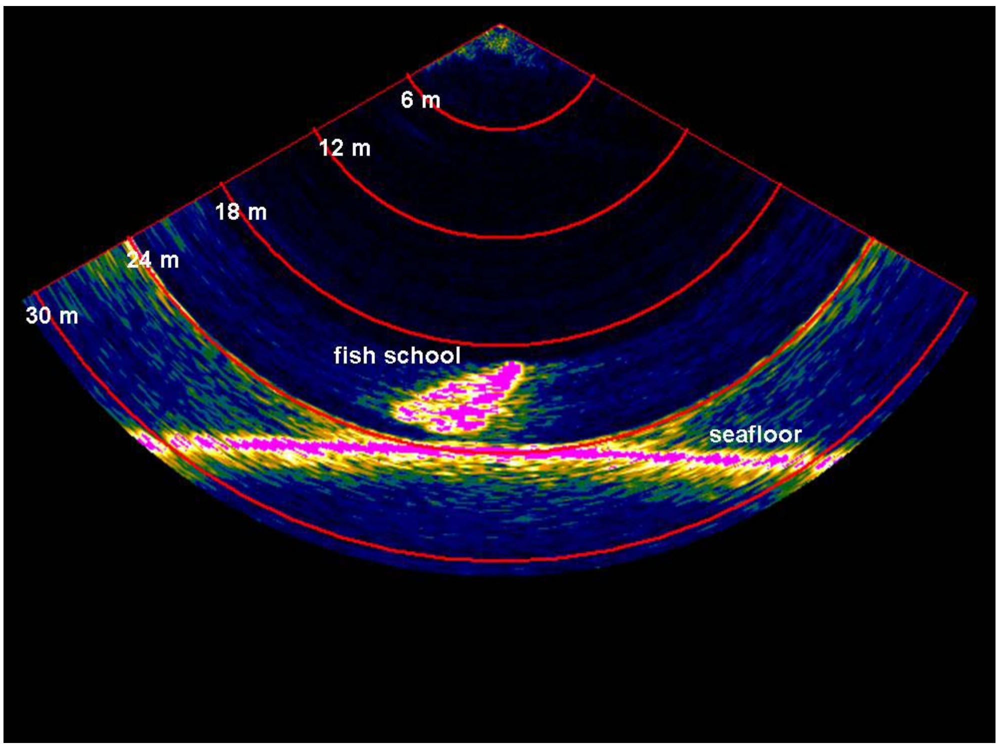

Figure 3. ***Backscattering at 200kHz from a single ping of a multibeam sonar. The seafloor is visible at about 24 m. A small school of fish approximately 10 meters wide by 4 meters tall is visible just above the seafloor. It is clear from this data that the fish are not uniformly distributed within the school as it appeared on the split-beam echosounder.***

IMPACT/APPLICATIONS

Patterns in biological distribution are often studied in relation to physical parameters and primary productivity. Numerous studies have demonstrated regulation of plankton by physical oceanographic processes. There has been limited research on biological causes of patchiness in the ocean:

reproductive, interactions between parents and offspring; social, intraspecific signaling between individuals; and coactive, intraspecific actions such as competition, predation and parasitism. This work will provide information on how predators and prey interact in the coastal ocean and will permit us to determine how these interactions affect the formation and maintenance of thin layers. This is critical for understanding how organisms within thin layers affect our measurements and for making predictive models about their distribution. In addition, this work will provide comparable, ship based acoustic surveys for ongoing optical work, giving us a unique opportunity to understand the relationship between acoustical and optical scattering. Combination of these results with direct samples will enable us to integrate acoustical and optical data to examine the possibility of the identifying scattering sources with the synthesized sonar and lidar data.

RELATED PROJECTS

This project is linked to those that are part of the *Layered Organization in the Coastal Ocean* DRI. Specifically, the projects of Holliday, Cowles, McManus, Prentice and Concannon.